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955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

B71 10011

date: October 19, 1971

to: Distribution

from: M. Liwshitz and N. P. Patterson

subject: Use of LRV TV for Scientific Observations
Case 340

ABSTRACT

A number of scientific objectives utilizing the LRV TV camera, such as observation of the solar corona and zodiacal light, appear desirable and attractive. However, study of the camera's capability reveals that, in its present configuration, the camera falls short of meeting the demands on sensitivity. In the present configuration the critical component is the color filter wheel, which reduces sensitivity by a factor of 50-100 and renders the camera less sensitive than the Surveyor TV system. The inherent sensitivity of the image intensifier vidicon used in the LRV TV camera makes it eminently suitable for low light level imagery -- its use as a star tracker in a guidance system is being considered -- but the LRV TV camera would have to be considerably modified to take advantage of this high sensitivity. Though some gain in signal to noise ratio may ensue from data processing, its cost should be realistically estimated in advance. Also, if the TV camera were committed to the scientific uses considered, this cannot be done in an ad-hoc fashion, but requires extensive testing and calibration. These are the conclusions derived from our analysis and from talks with both scientists and engineers familiar with different aspects of the problem.

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MEMORANDUM FOR FILE

I. Introduction

Shortly before the launch of Apollo 15 it was proposed that the Lunar Rover TV camera be used for a number of scientific observations subsequent to the LM ascent stage liftoff.[1] In particular, the coincidence of the post-liftoff period with an eclipse of the sun by earth was thought to offer an opportunity for a variety of observations of both public and scientific interest. Malfunction of the camera system cut short its operation prior to the eclipse and none of the seemingly attractive opportunities could be realized.

From the list of scientific TV objectives proposed for Apollo 15 one can single out as most valuable the observations of the solar corona and zodiacal light. Fortunately, these do not require occultation of the sun, but could be carried out on the remaining Apollo missions by the TV camera looking over the horizon after sunset or prior to next sunrise, if battery power is not depleted by then and if other conditions are met. Foremost is, of course, the capability of transmission to earth, which requires an automatically pointed high gain antenna. As we understand it, provision for such a pointing system has been considered for other reasons.[2] The other necessary condition is the qualification of the camera for this type of observation on the remaining missions.

Though in the following we address ourselves mainly to corona and zodiacal light, we will refer in passing to some of the irretrievably lost observations from Apollo 15 that depend on the presence of an eclipse, inasmuch as these illuminate the sometimes fuzzy borderline between scientific and primarily public interest observations. In doing so, we wish by no means to denigrate public interest, but, in weighing alternatives for action with regard to the TV camera, practical reasons indicate that the two should not be confused: screening of TV pictures of purely public interest is a complete and self-contained activity; useful return from scientific TV observations calls for investment of considerable resources subsequent to acquisition of the pictures.

In its present configuration the LRV TV would be of marginal utility in observing the faint luminosity of the extended solar corona and the zodiacal light. To assess the need for modifications we present the following sections that deal with the LRV TV camera characteristics and the observational requirements.

II. The LRV Camera

For our purposes the characteristics of interest are the camera's resolution and sensitivity.

A. Resolution

Table I[3] presents the relevant operational parameters of the TV camera. Vertical resolution is fixed by the $\sim$500 scan lines/frame, horizontal resolution is determined by the $\sim$2 MHz transmission bandwidth which, at 80 lines/MHz, provides $\sim$160 lines. (Commercial TV uses $\sim$4.5 MHz for $\sim$500 lines.) Actually, horizontal resolution is reduced by the field sequential color system used, but no exact numbers on this reduction are available. The camera spans focal ratios from f/2.2 to f/22 with corresponding fields of view of $\sim 32° \times 43°$ and $5.25° \times 7.00°$. Consequently, in the narrow field configuration the angular field of a resolution element is $\sim .63' \times 2.6'$, or $\sim (1.8 \times 7.5 \times 10^{-8})$ sterad. No astronomical objects except earth and the sun fill more than a single resolution element of the TV camera. At 5 m distance the effective dimensions of a resolution element are then about 1 mm x 4 mm, at the distance of the earth the dimensions are $\sim$72 km x 300 km and at solar distance the dimensions are 27,000 km x 110,000 km. Though this poor resolution at astronomical distances would not have precluded a spectacular view of the earth's atmospheric halo during the solar eclipse, it deprives such observations of any serious scientific value, if such value is attached to the acquisition of new and better data with some quantitative content, and not just the production of beautiful photographs. On the other hand, observation of extended astronomical objects that do not require high spatial resolution, would be valuable, provided the camera has sufficient sensitivity.

B. Sensitivity

Talks with Messrs. Russel, Barna and Masucci of RCA, all involved in design and development of the LRV TV camera, indicated 9.3 Ft-L as the lower limit of scene luminance that can be accommodated by the camera in its present configuration, which includes the color wheel. The latter degrades sensitivity by a factor of ∿80. For comparison, the lower limit of scene luminance accommodated by the Surveyor TV camera[4,5] -- which differed greatly in design and operation -- was 8×10^{-3} Ft-L. This would indicate that the present LRV TV camera is ∿40 times less sensitive than the Surveyor camera. In the high sensitivity integrating mode, adapted to the special vidicon used in the Surveyor TV camera, the latter could record sixth magnitude stars. From the sensitivity ratio of the two cameras, we thus obtain for the LRV camera, in its present configuration, a detection limit of second magnitude stars. It should be noted, however, that the LRV TV camera vidicon itself is very sensitive. Removal of the filter in laboratory tests provided for detection of 8th magnitude stars in a 1 sec exposure of polaroid film to the TV picture. This is consistent with our estimates based on the sensitivity ratio of the two cameras.

III. Instrumental Requirements for Scientific Observations

It appears that two types of post-liftoff scientific observations merit serious consideration, namely, lunar surface observations and observations of the solar corona and zodiacal light. The requirements of lunar surface observation are probably met by the present TV camera configuration with minor modifications and correction of obvious defects, such as clutch slippage and thermal control. Apart from a look at throwout from the LM impact -- and its visibility to the camera has to be demonstrated -- surface observations are not exciting as science; repetition of rock color measurements carries no pro-promise of new knowledge. On the other hand, according to Dr. Weinberg of Dudley Observatory, any good measurements of the solar corona at elongations between 5 and 30 degrees, that is, beyond ∿20 solar radii, would constitute a valuable contribution to present knowledge.

IV. Measures for Improving the Rover TV Camera Sensitivity

The above results show that for observation of zodiacal light, which we believe to be the potentially most valuable post-liftoff scientific objective, the sensitivity of the camera has to be increased by a factor of at least 10^3. How can this be achieved without complete redesign of the camera system? An obvious means of enhancing effective sensitivity, limited by signal to noise ratio, is integrative data processing. A priori, superposition of n consecutive frames should result in an $\sqrt{n}$-fold increase in signal to noise ratio. Moreover, this method suits, in principle, extended objects that change slowly, like the zodiacal light field as viewed from the moon. Yet, clearly, data processing cannot achieve the required improvement by a factor of 10^3 to 10^4 at 30 frames/sec: this would entail the obviously absurd integration of $\sim$5-hour records. On the other hand, it certainly is worthwhile to find out whether a 100-fold improvement, requiring integration of 10-minute records, is a realistic target.

The limiting factor in integrative data processing is coherent noise. According to the RCA staff members contacted, coherent noise sources are present in the TV system due to imperfections in the vidicon and associated circuitry. This coherent noise eludes, however, theoretical prediction, and has to be experimentally determined in each individual TV camera system. In fact, the noise pattern at low light levels for every camera has to be mapped for later subtraction from integrated TV records. According to Dr. Page of MSC, post facto data processing attempts of Apollo 15 TV tapes have encountered difficulties related to this problem. To reduce the potentially high cost of integrative data processing and to reap its full benefits, extensive tests have to be completed before committing additional resources to an observation program. But even if tests should bear out expectations of a significant, say even hundredfold, increase in performance, the LRV TV camera in its present configuration would appear to be deficient in required sensitivity.

The case might be rested here; however, use of the LRV TV camera for low light level astronomical observations in a remote control mode appears not only attractive in its own right, but appears valuable as a prototype for similar operations should there someday be an unmanned sequel to

Apollo. Plausible means for improving performance should be, therefore, explored. But it has to be borne in mind that no further improvement seems likely without some measure of tampering with the present camera configuration. This is a prospect that may be costly and hard to implement in view of the short time left before the remaining Apollo launches.

Acknowledgements

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M. Liwshitz

N. Paul Patterson

N. P. Patterson

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Attachment
Table 2

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1. MSC Internal Memorandum, "Operations and Data Analysis Plan for Post-Liftoff Use of Color TV Camera on Apollo 15 Mission," July 8, 1971.

2. Heiber, A., "Feasibility of High Gain Antenna Pointing System," Bellcomm Memorandum for File (B71 08020), August 17, 1971.

3. Anon., "Apollo 15 Television Test Team Report, Vol., NASA-MSC, 1971.

4. Anon., "Surveyor Program Results," NASA SP-184, 1969.

5. Surveyor Project Staff, "Surveyor Project Final Report," Chapter XXII, NASA-JPL Technical Report 32-1265, 1969.

TABLE I

CTV Operational Parameters

Television Parameters	Operational Value
Camera Type	Field sequential color using a single image tube with a rotating color filter wheel.
Output Response	Flat within ±2dB, DC to 2 MHz.
Frame Rate (Nominal)	30 per second (60 fields per second).
Active Scan Lines per Frame (Nominal)	525
Output Spp/Nrms	35 dB (min.) within 2 MHz BW
Lens	12.5 - 75 mm (zoom)
Resolution	80 TV lines/MHz (bandwidth)
Output Voltage	1 volt (max.) ±5%, and 1.4 volts (max.) ±5% for NMT 1 second period.
Aspect Ratio	4:3 Horizontal-to-Vertical
Gray Scale	7 minimum (Electronics Industry Association Resolution Chart)
Line Frequency	15,734.26 Hz ±0.01%
Interlace Ratio	2:1
Filter Wheel Color Sequency	Red - Blue - Green (RBG) (One Color per Field)
Light Range	3 - 36,000 foot-candles
Iris Range	f/2.2 - f/22

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